

MCNP6: Fission Multiplicity Model Usage in Criticality Calculations

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Slide 1

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Outline

■ Background

- Why Fission Multiplicity in MCNP6?
- Current Capabilities/Limitations

■ Nuclear Criticality Safety

- Relevant Applications
- Numerical Results

■ Conclusions

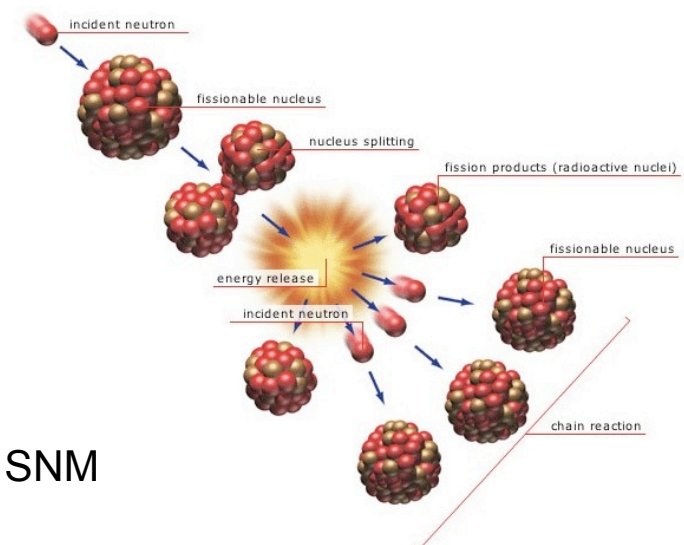
- Preliminary Thoughts
- Next Steps

Background:

Why Fission Multiplicity in MCNP6?



- Currently funded NNSA / NA-22 venture project with LANL / LLNL / LBNL / Univ. of Mich for weapons material security
- Application of interest (fixed source)
 - Global security and nuclear nonproliferation
 - Detection of special nuclear material (SNM)
 - Passive and active interrogation techniques
 - Coincident neutron and photon leakage
- Key issues
 - Average nuclear data quantities are insufficient
 - Cannot predict correlated signatures of shielded SNM
- Approach to obtain predictive capability
 - Use transport code MCNP for modeling neutrons and photons
 - Fission event generators are under development (FREYA & CGMF)
 - Implement in MCNP and compare to experiment



Background: Current Capabilities/Limitations



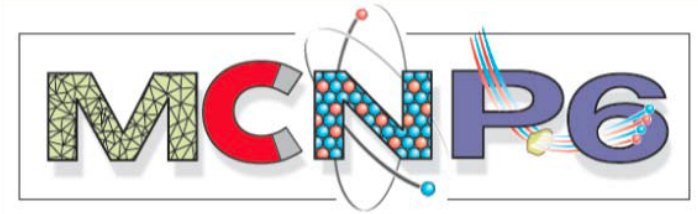
■ Default MCNP6 secondary emission physics:

- Neutrons – integer sampling
- Photons
 - Based on total photon production data
 - Emission determined before type of reaction is known
 - Integer number of photons changes with isotope, energy, etc.
- **No correlations** between emitted particles

■ Parallel processing:

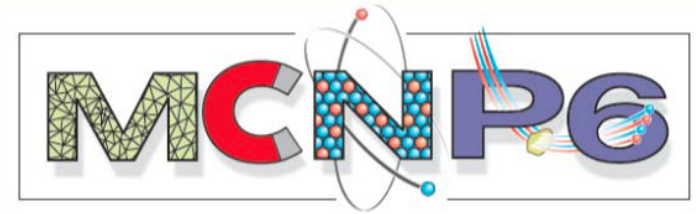
- OMP threading **disabled** for certain features
 - Most MCNPX physics models
 - High-energy physics like CEM, LAQGSM, INCL, ABLA, etc.
 - Multiplicity packages CGM & LLNL Fission Library
 - Delayed particle physics from CINDER
 - PTRAC (list-mode style output) and event logging

Background: Current Capabilities/Limitations



- Neutron multiplicity for fission is based on **expected value** of $\text{wgt} \cdot \nu \Sigma_F^{\text{mat}} / \Sigma_T^{\text{mat}}$ neutrons per collision in the material
 - If more than 1 neutron, the energy & direction for each are sampled **independently** (no correlation)
- The spectrum used for the fission neutrons is randomly chosen using probabilities $\nu \Sigma_F^{\text{iso}} / \nu \Sigma_T^{\text{mat}}$ for the nuclides in the material
 - Energy is sampled using ENDF spectrum data for the selected nuclide
 - Prompt vs delayed neutron selected first, then energy
 - If more than 1 neutron, energy is sampled **independently** for each one (no correlation), using the same spectrum data
- The direction for fission neutrons is sampled **isotropically**
 - If more than 1 neutron, directions are sampled **independently** for each neutron (no correlation in direction)
- For KCODE problems with photons, photons are sampled **independent** of neutrons (no correlation between neutrons & photons)

Nuclear Criticality Safety: Relevant Applications



■ From the fixed-source, SNM detection perspective...

- Experiments are underway to test the predictive capability of these models
- Generally, benchmarked experiments that can validate these models are **unavailable** ...
- ... think neutron-photon coincidence experiments with SNM
- Need some **validated benchmarks** that use fission event generators

■ From the criticality safety community perspective...

- Traditional MC work has focused on k-effective, reflector & control material reactivity, etc.
- The reactor physics community has traditionally used MC for k-effective, power distributions, control material reactivity, etc.
- Vast collections of V&V data, MC vs benchmark experiments
- **No V&V work has been done to date on using explicit fission neutron multiplicity options in MCNP for criticality safety or reactor physics applications**

Nuclear Criticality Safety: Relevant Applications



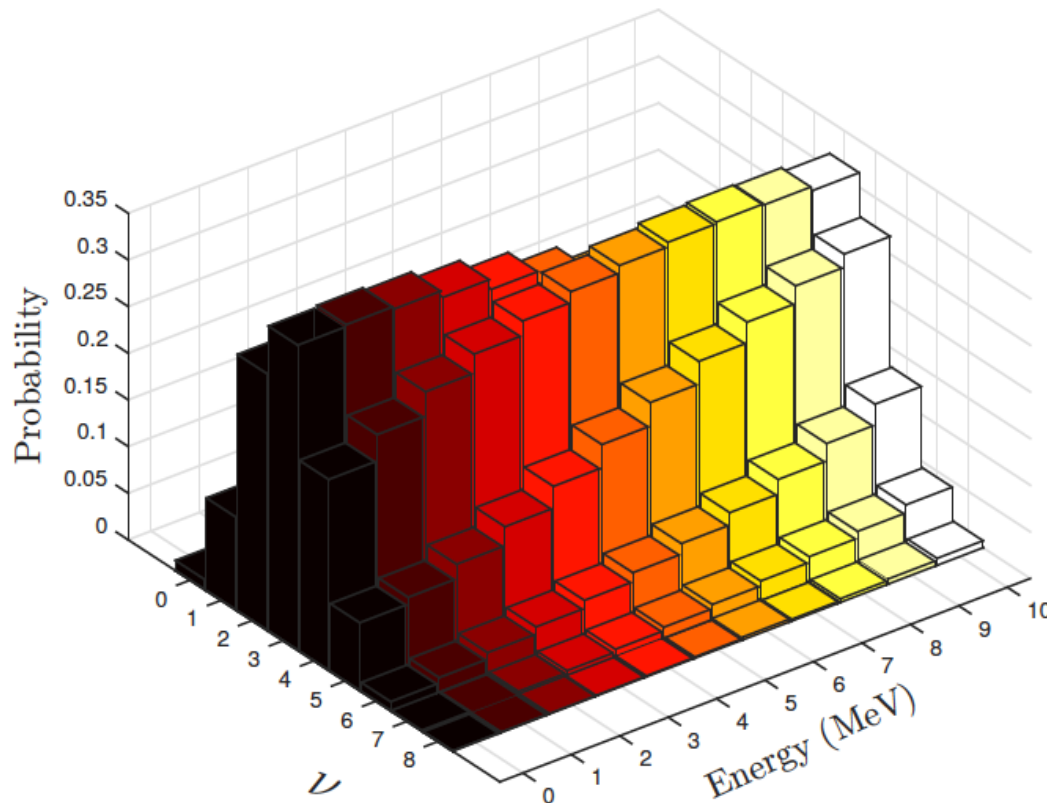
- **Investigate impact on criticality calculations (NCSP support)**
 - Graduate student research project – **Mario Ortega at UNM**
 - Evaluate and explore potential use of fission event generators for NCS
- **Existing MCNP6 features**
 - Fission event generators already in MCNP (NA-22 venture project)
 - **Extensive V&V** benchmark test suites available in MCNP already
 - Covers many actinides and fast, intermediate and thermal systems
 - Small benchmark test suite with 31 tests
 - Medium benchmark test suite with 119 tests
 - Large (Whisper) benchmark test suite with > 1000 tests (not used here)
- **Changes from MCNP6 default criticality calculations**
 - **Analog** transport to explicitly sample fission events
 - Fission bank resampling at end of each cycle = fixed number of neutrons per cycle
 - Turn on fission multiplicity models **with threading**

Nuclear Criticality Safety: Numerical Results

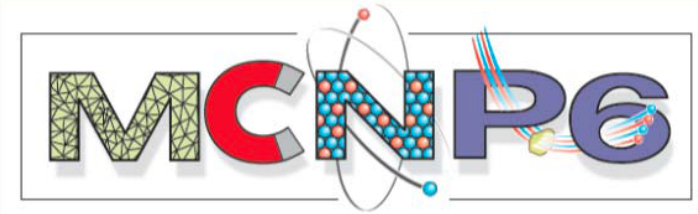


■ Multiplicity distribution

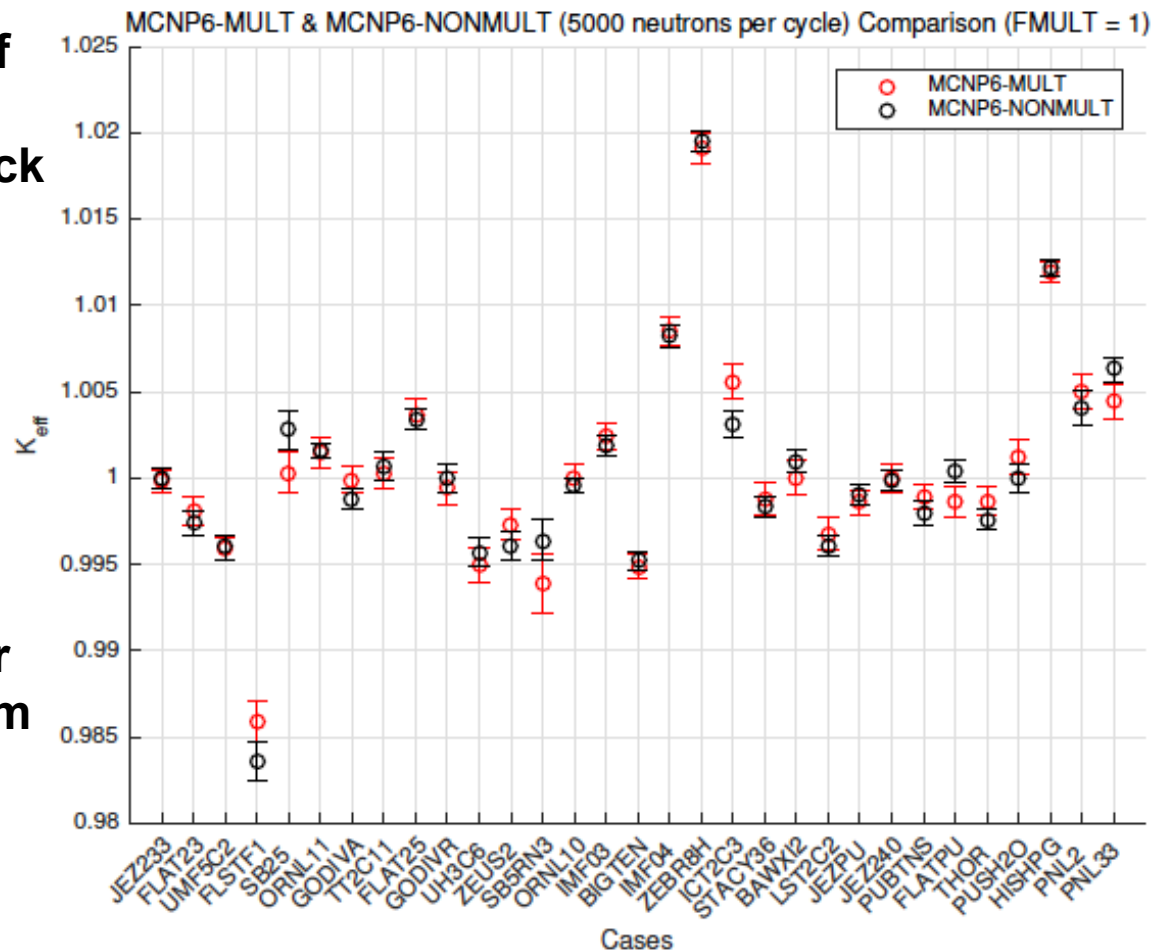
Induced Fission Neutron Multiplicities for Plutonium-239



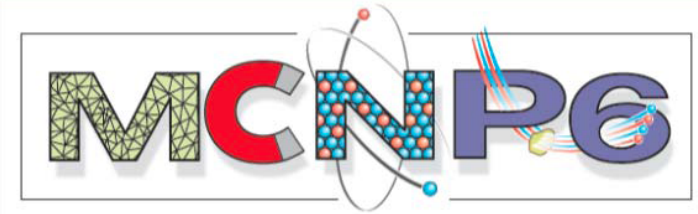
Nuclear Criticality Safety: Numerical Results



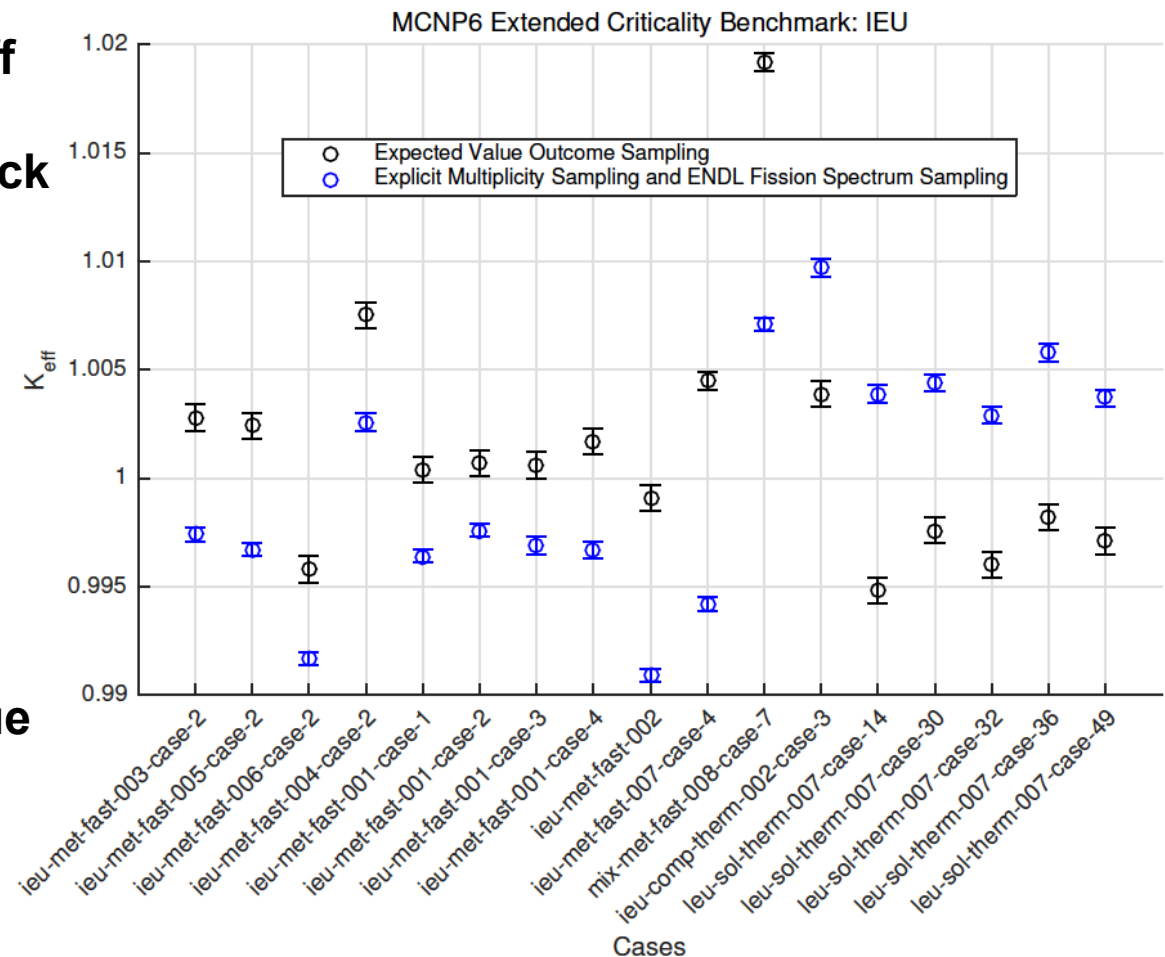
- Critical benchmark K-eff results using default MCNP6 approach in black and ...
- ... using LLNL Fission Library neutron multiplicities in red
- Nubar is preserved in LLNL Fission Library
- Both using ACE data for fission neutron spectrum sampling
- Statistically equivalent



Nuclear Criticality Safety: Numerical Results



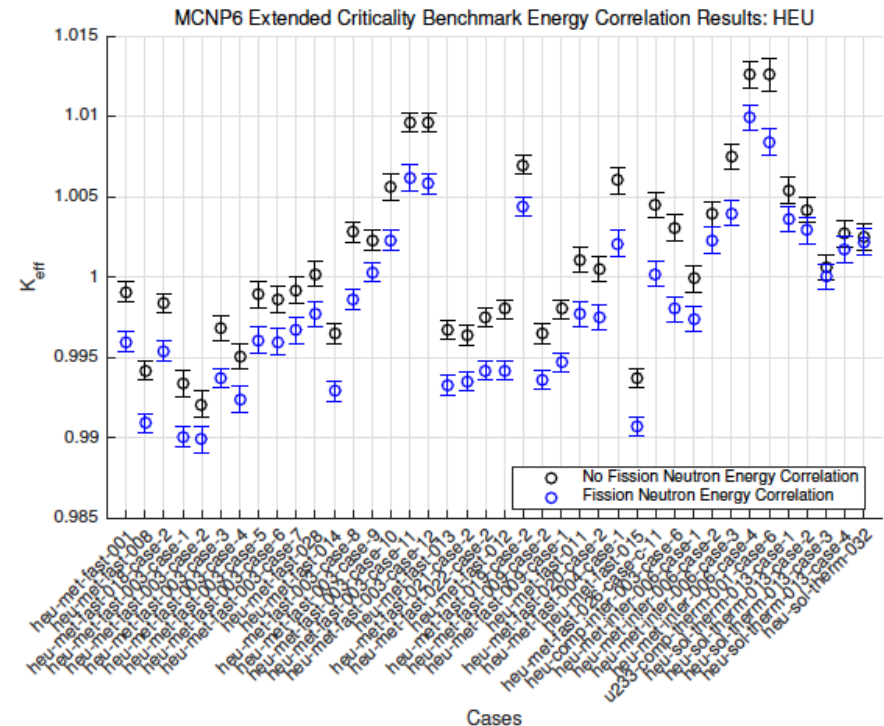
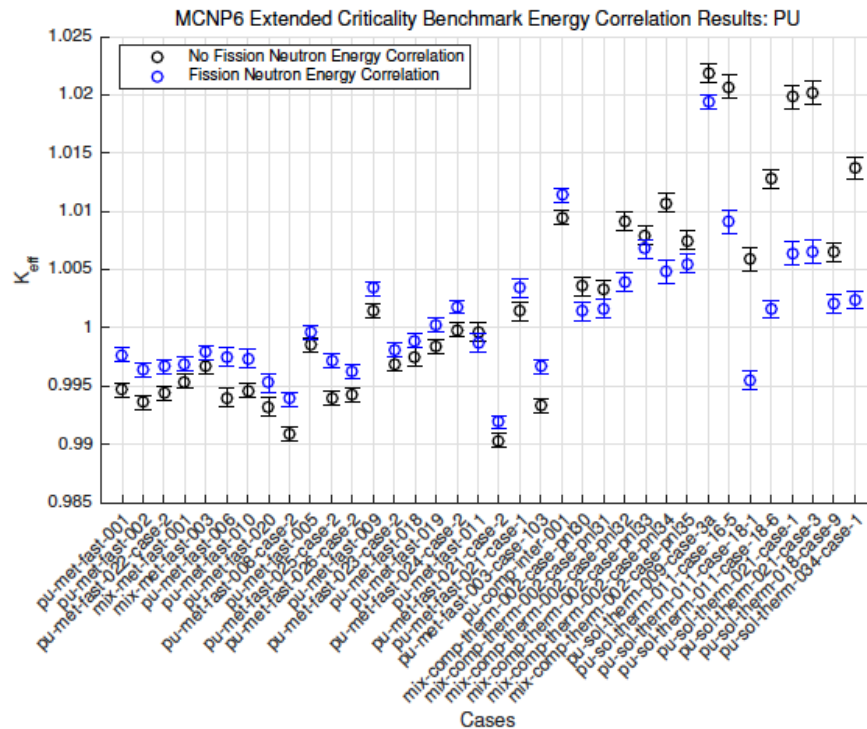
- Critical benchmark K-eff results using default MCNP6 approach in black and ...
- ... using LLNL Fission Library neutron multiplicities and spectrum (Watt) in blue
- Nubar is preserved in LLNL Fission Library
- Statistically different due to change in spectrum



Nuclear Criticality Safety: Numerical Results



- Critical benchmark K-eff results using default MCNP6 approach in black and using LLNL Fission Library neutron multiplicities in blue
- Neutron energy correlations due to total neutron energy constraint

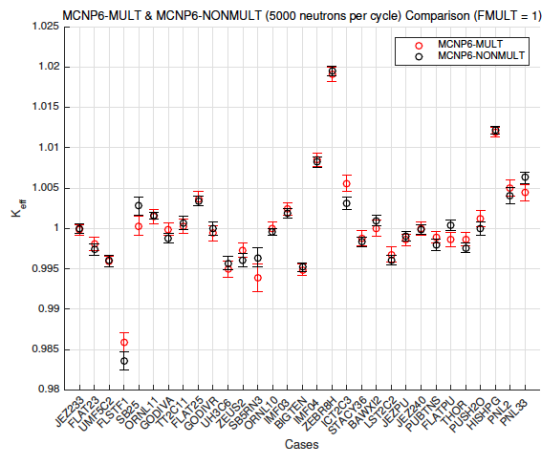


Conclusions: Preliminary Thoughts



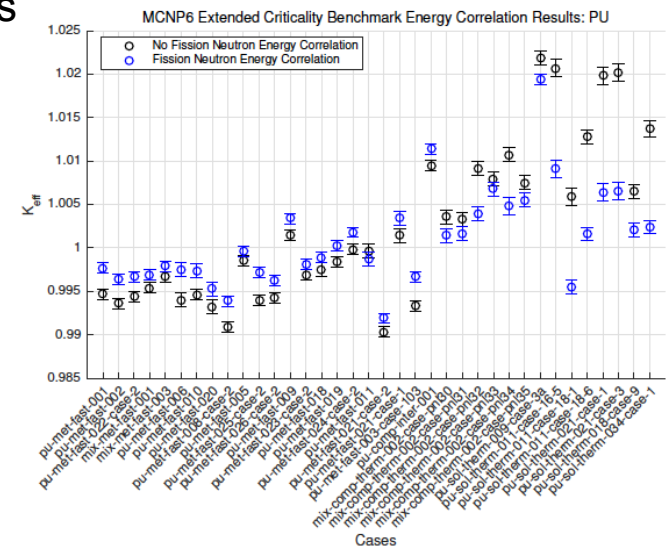
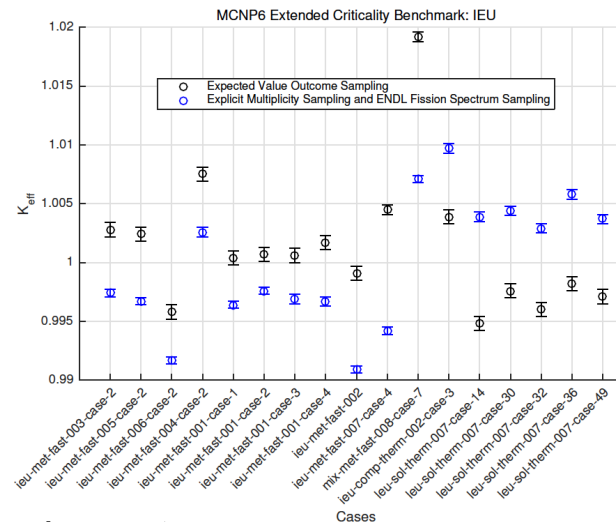
■ Criticality Validation Test Suite

- 31 experimental benchmarks
- Covers several materials, compositions & energy ranges



■ Extended Criticality Validation Test Suite

- 119 experimental benchmarks
- LEU, IEU, HEU, U233 and Pu materials, compositions & energy ranges

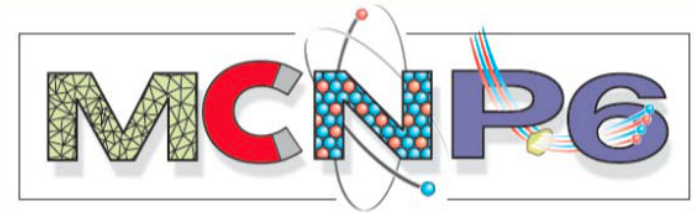


■ Punchline:

- multiplicity → *no impact
- spectrum → definite impact

- energy correlation → ???

Conclusions: Preliminary Thoughts



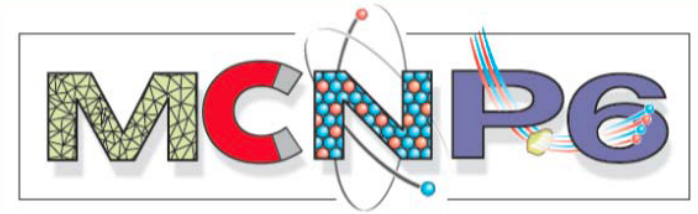
■ Accomplishments:

- Mario Ortega, graduate student at University of New Mexico, completed M.S. in Nuclear Engineering in Fall 2015 – “Fission Multiplicity Distribution Sampling in MCNP6 Criticality Calculations”
- Mario I. Ortega, Michael E. Rising, Forrest B. Brown and Anil K. Prinja, “Fission Neutron Multiplicity in MCNP6 Criticality Calculations,” to be presented at PHYSOR 2016 in Sun Valley, ID.

■ Preliminary numerical results are suggestive

- From fixed-source, SNM detection perspective...
 - Fission event generator developers should strive to obtain acceptable results in the area of criticality safety applications
 - Would require (nearly) reproducing nubar and spectrum from ENDF
- From criticality safety perspective...
 - Should **NOT** use LLNL Fission Library v. 1.8 for NCS applications
 - Open question: How do the neutron energy (or possible angular) correlations impact NCS applications?

Conclusions: Next Steps



- **MCNP 6.2 will include new fission multiplicity models as part of a NA-22 venture project, “Developing Accurate Simulations of Correlated Data in Fission Events”**
 - LLNL Fission Library upgrade from version 1.8 to 1.9 with FREYA
 - New CGMF model from LANL’s T-Division
 - Use in criticality (KCODE) problems **will not be allowed**
 - Run criticality validation tests with these new models and re-evaluate

- **On the horizon,**
 - More neutron and gamma-ray timing information from models
 - Experimental validation of multiplicity models (coincident angular/multiplicity correlation measurements underway)
 - New research in incident-outgoing neutron angular correlations



Acknowledgements



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